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Abstract

STABILITY ANALYSIS AND DYNAMIC PERFORMANCE OF A CHEMICAL SYSTEM OPERATED FOR THE AUTOMATIC FINE CONTROL OF A NUCLEAR REACTOR

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An automatic fine control system has been designed and satisfactorily operated, where the regulating rod and velocity servo are replaced by a boric acid solution circulating in a tube near the reactor core.

Any reactivity variation up to 200 pcm is obtained by injecting pure water or a concentrated boric acid solution into the main hydraulic circuit. This circuit is of the closed-loop type and an expansion tank with an overflow is provided for removing the excess flow during reactivity transients.

A control of the reactivity by means of soluble poison instead of conventional solid-state absorbers offers many advantages, in both power and research reactors. Nevertheless, some additional problems must be dealt with, involving the chemistry of acid solutions, the behaviour of materials and the system dynamics.

Dynamic stability and performance analysis are two of the main factors in the design of a chemical system suited to the fine control of nuclear reactors

This paper illustrates in detail the study performed on a linearized model of the actual system by using the conventional graphic and analytical method of the feedback system theory.

Calculations were made with the aid of an IBM-704 digital computer and the Nyquist diagram was obtained for the open-loop transfer function of the whole system.

Some typical features of a closed-loop circulating soluble poison control system are:

1. A strongly variable gain of the system in function of the value of operating steady-state concentration. This is due mainly to the different effects obtained by injecting an equal amount of water or concentrated boric acid solution; obviously a higher pure-water effect is obtained on increasing the solution concentration - and the opposite happens in the case of a boric acid injection.

   Another effect results from the non-linear characteristic of the reactivity versus concentration diagram for a U-shaped tube employed in the in-pile section because of the self-absorption phenomena occurring at elevated values of boric acid concentration.

2. The time delays caused by the flowing of the solution have two major effects which strongly influence the dynamic behaviour of the system. Firstly, the delay between the injection point and the reactor compromises the system stability being equivalent to a long-time constant; secondly, a tendency towards self-sustaining oscillations is observed at $\frac{1}{T}$ frequencies, where T is the total transit time.

For obtaining a control loop with a dynamic performance similar to that of a conventional mechanical rod drive and velocity servo-system, proportional, integral and derivative controllers were found to be inadequate and a more elaborate network was designed.

The validity of the linear model is then checked by simulating the whole system on an analogue computer; some non-linear effects, such as the valve opening saturation, are found to be important in reactor transients involving heavy reactivity insertions, and more precise controller parameter values are obtained.

The control system was successfully tested and operated on the AVOGADRO reactor. Power transients typical of a research reactor routine operation were performed, as for instance reactivity insertions and variations in power demand and a precision higher than 1% was obtained in the neutron flux level regulation.

The transfer function of the system was also measured and the experimental points were in excellent agreement with the Nyquist diagram.